



Orderly grid connection of renewable energy generation in China: Management mode, existing problems and solutions



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ABSTRACT

With the increasingly severe global environmental problems and the decrease of the storage of the fossil energy, renewable energy sources (RES) are drawing more and more attention. In China, renewable energy generation (REG) is experiencing a rapid development; however, its investment, transmission and management remain immature and deficient compared with those of the developed countries. First, this paper summarises the developing situation of REG in China through taking the booming wind power and photovoltaic power as examples, indicating that the grid connection rate of REG has yet to be improved. Then, this paper focuses on the grid connection management mode of REG in China which includes the following aspects: operation management, organisation management and grid connection incentive policy. Third, based on the above research, this paper analyses the existing problems of the grid connection management mode of REG. Finally, a coordinated management mechanism is proposed to solve the problems impeding large-scale grid connection of REG in China, including the coordinated management mechanism of integrated planning and transmission.

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1. Introduction

RES are an important part of the energy system, with the features of wide distribution capability and great development potential. Renewable energy sources are environmentally friendly and sustainable compared with conventional energy sources. Therefore, the exploitation and utilisation of RES has been an important measure in the world to ensure energy security and to tackle climate change [1]. The central government of China has issued the requirement that the proportion of the annual use of RES to the total energy use should reach 9.5% in 2015 and 15% in 2020 [2].

In recent years, with the promotion of power system reform in China, the development of renewable energy generation (REG) is increasing markedly [3]. Large-scale development of REG will be the significant measure used to comply with the requirements of low-carbon electric power development and to guarantee national energy security. On the one hand, RES can replace traditional fossil energy to decrease the emission of pollution by fossil fuel burning. On the other hand, the coordinated transmission of RES and traditional energy can improve the utilisation efficiency of energy effectively. In addition, the renewability character of RES can effectively relieve the shortage of energy supply and guarantee the national energy supply security [4,5]. However, as the grid connection of REG in China is still in its early stages, there are many problems concerning grid connection operation management, organisation management and grid connection incentive policy that impede the large-scale development of REG, such as how to re-plan the grid to adopt more REG, how to provide reasonable compensation for the grid's adoption, who have the right to invest wind power plants as well as the rights and liabilities of all parties during the grid connection process, the testing and certification mechanism has not yet been established and so on. Complying with the higher share of REG among power supply structure, these questions have hindered the orderly grid connection and healthy development of REG severely [6,7]. Therefore, it is of great significance to study the grid connection issue of REG.

We can see that scholars have done some research on the issue of grid connection of REG in China. However, the research is generally broad and not deep enough. First, the rights and liabilities of each participant has not been subdivided explicitly. Second, the coordinated operating mechanism between REG power sources and other factors (such as traditional power sources, peak-shaving power sources, power storage devices and power grid) has not been analysed profoundly. Third, the function of demand-side response (DSR) for promoting the adoption of RES has not been considered. Fourth, the clear management process has not been designed. Taking above deficiencies into consideration, this paper establishes coordinated management mechanism for the orderly grid connection of REG based on the resource distribution, technological level and power system of China. The study of this paper will have profound guiding significance for the practical work.

The structure of this paper is as follows: first, this paper describes the current development situation of REG in China, with a focus on the analysis of wind and solar power, whose development scales are relatively larger and rates of development are relatively high. Second, this paper studies the management mode of grid connection from the aspects of operation management, organisation management and grid connection incentive policy. Finally, this paper proposes a coordinated management mechanism to implement an orderly deployment of grid-connected REG in China.

2. A review of REG planning and development in China

Benefiting from the *Renewable Energy Act* and the relevant policies, REG has been enjoying rapid development. Currently, wind and solar power generation are the two most important

non-conventional renewable energies because hydropower is defined as conventional REG. On the one hand, by the end of 2013, China's power installed capacity of wind and solar power was 91.41 GW and 19.42 GW, respectively, in which approximately 75.48 GW and 14.79 GW was grid-connected. On the other hand, the consumption of clean energy is 1.21 million GWh in China, among which the consumption of wind and solar power are separately only 131.90 thousand GWh and 11.90 thousand GWh [8].

2.1. Planning and development of wind power in China

Wind power in China has experienced rapid growth for many years and is currently in a steady development stage. By the end of 2013, the newly installed wind power capacity was 16.09 GW, and the cumulatively installed wind power capacity was 91.41 GW, in which the percentage of installed capacity that is grid-connected was 84.87%. The growth trend and situation of the grid-connected capacity [9] are described in Fig. 1 and Table 1, respectively. From the geographical point of view, the level of development for wind power in the Inner Mongolia Autonomous Region is the highest, of which the total installed capacity is 20.27 GW. The next 3 provinces with high levels of REG development are Hebei province, Gansu province and Shandong province, each with over 6.98 GW of total installed wind power capacity [10].

In Table 1, the rate of grid-connected wind power in China has been approximately 70–80% of the installed capacity in recent years and is increasing. However, there is still a gap between China's level of grid connection and that of other developed countries.

The most characteristic scheme for wind power development is “the Three Gorges of wind power” that was proposed in 2008 and was proven to be suitable for China's current situation of energy demand and wind power resources [11]. In the scheme mentioned, seven wind power bases, each with 10 GW of installed capacity,

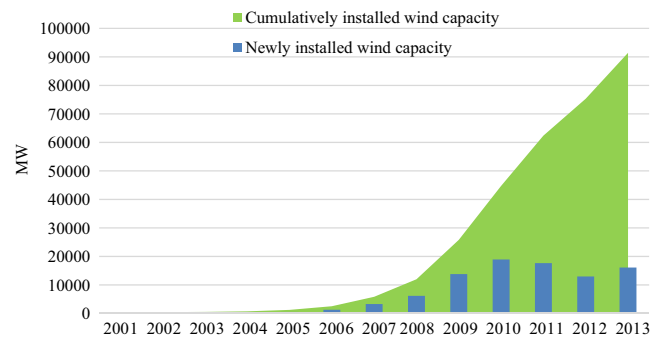


Fig. 1. Newly installed wind capacity and cumulatively installed wind capacity in China from 2001 to 2013.

Table 1

Data for the installed capacity of grid-connected wind power in China.

Year	Installed capacity of wind power (MW)	Installed capacity of grid-connected wind power (MW)	Rate of grid connection installed capacity (%)
2005	1250	1056	84.48
2006	2537	2072	81.67
2007	5848	4200	71.82
2008	12,002	8940	74.49
2009	25,805	17,670	68.48
2010	44,733	31,070	69.46
2011	62,364	47,000	75.36
2012	75,324	62,370	82.80
2013	91,412	77,580	84.87

would be built at Jiuquan of Gansu province, Hami of the Xinjiang Uygur Autonomous Region, the western Inner Mongolia Autonomous Region, the eastern Inner Mongolia Autonomous Region, Jilin province, Hebei province, and the coastal areas of Jiangsu province. The total planned installed capacity will be 90.17 GW, accounting for approximately 78% of the total capacity in China. After that, in December of 2010, an offshore wind power base in Shandong province with the same scale of the seven bases was planned [12]. So far, China has formed a centralised wind power development mode with eight ten-GW class wind bases, as shown in Fig. 2.

The development of offshore wind power in China was launched in 2008 [13], with plans for the development of offshore wind power in the provinces of Shanghai, Jiangsu, Shandong, Hebei, Zhejiang, Guangzhou completed, and plans for development in Liaoning province, Fujian province, Guangxi Zhuang Autonomous Region, Hainan province and other provinces are currently ongoing [14–16]. The completed plans correspond to 43 GW of offshore wind power capacity, of which preparatory work of 38 projects is currently being implemented, amounting to 16.5 GW in capacity.

2.2. Planning and development of solar power in China

With a vast territory and good geographic location, China has abundant solar energy resources. The average annual radiant quantity of solar energy is between 3340 MJ/m² and 8400 MJ/m², with the median-value of 5852 MJ/m² [17]. As for the distribution of solar energy in China, the western area has the largest radiant quantity because of geographical factors. The resource distribution of solar energy [18] is shown in Table 2.

In recent years, with the development of technology and the incentives of policy, the solar power market in China is diversified, including large-scale photovoltaic (PV) power plants, solar thermal power plants, distributed PV power generation and off-grid PV systems. The total installed solar power capacity was 19.42 GW in 2013, of which 14.79 GW was grid-connected [19].

The National Development and Reform Commission (NDRC) implemented a feed-in tariff of PV power generation in 2011, greatly promoting the construction of ground PV power stations in the western areas with abundant solar resources [20]. Among the recently constructed PV power generation projects, the capacity

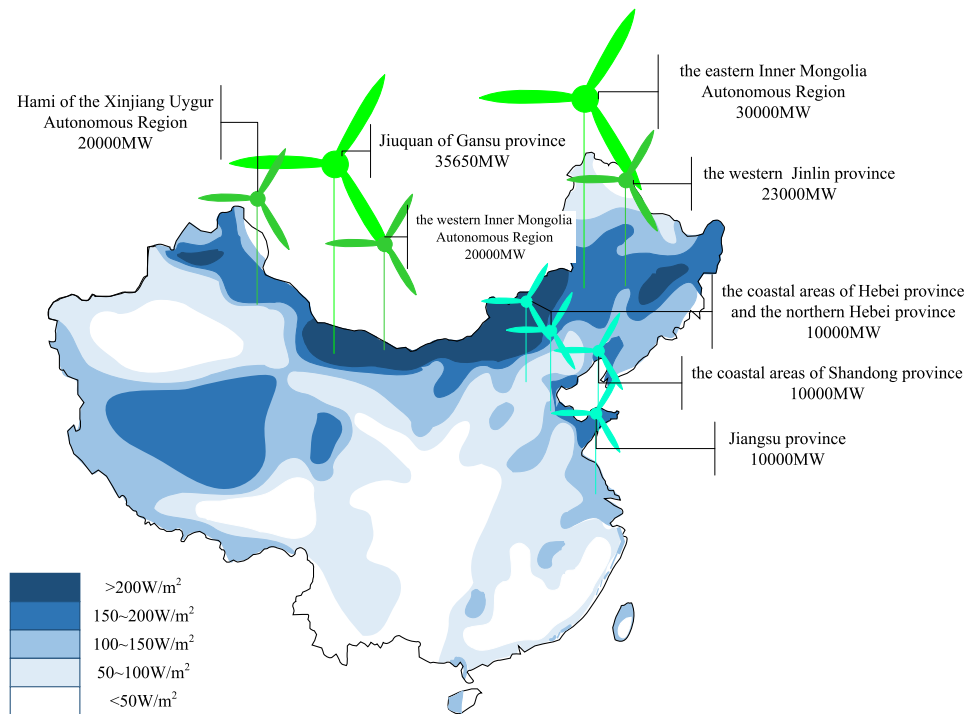


Fig. 2. Distribution of eight large-scale wind power bases and their installed capacity (planned by 2020).

Table 2
Distribution of solar energy in China.

Classification	Radiant quantity (MJ/m ²)	Distribution
Class I,	6680–8400	Northern Ningxia Hui Autonomous Region, northern Gansu province, eastern Xinjiang Uygur Autonomous Region, western Qinghai province, and western Tibet Autonomous Region
Class II	5850–6680	West-north of Hebei province, northern Shanxi province, southern Inner Mongolia Autonomous Region, southern Ningxia Hui Autonomous Region, middle of Gansu province, eastern Qinghai province, south-east of Tibet Autonomous Region, southern Xinjiang Uygur Autonomous Region, etc.
Class III	5000–5850	Shandong province, Henan province, Hebei province, southern Shanxi province, northern Xinjiang Uygur Autonomous Region, Jilin province, Liaoning province, Yunnan province, northern Shanxi province, south-east of Gansu province, southern Guangdong province, southern Fujian province, northern Jiangsu province, northern Anhui province, and south-west of Taiwan province
Class IV	4200–5000	Hunan province, Hubei province, Guangxi Zhuang Autonomous Region, Jiangxi province, Zhejiang province, northern Fujian province, northern Guangdong province, southern Shanxi province, northern Jiangsu province, southern Anhui province, Heilongjiang province, and north-east of Taiwan
Class V	3350–4200	Sichuan province and Guizhou province

Table 3

Development overview of regional MW-class PV power plants in China.

Regions	Specific location	Overviews
Northwest China	Dunhuang, Gansu province	Two 10 MW PV power generation demonstration projects with a total investment of ¥0.473 billion and an expected annual generation of 32.74 GW
	Suzhou district, Jiuquan	PV power generation demonstration base with a total installed capacity of 1 GW by 2020
Yunnan province	Qaidam Basin, Qinghai province	20 PV power plants with a total installed capacity of 2308 MW
	Shilin	Grid-connected PV demonstration power plant with a total installed capacity of 166 MW and an expected annual power generation of 195 GWh
Tibet Autonomous Region	Yangbajing	A total installed capacity of 10 MW with an expected total power generation of 430 GWh over its entire service life
Northeast China	Jinzhou, Liaoning province	An annual power generation of 420 MWh with a reduction of 252 t carbon emission
	Mudanjiang, Heilongjiang province	An annual power generation of 30 GW
North China	Erds, Inner Mongolia Autonomous Region	The future largest PV power plant in the world, accounting for 10% of the entire domestic market
East China	Jining, Shandong province	Designed generation capacity of 30 MW with an international advanced thin-film solar PV technology
	Hefei, Anhui province	The second grid-connected PV power plant with an installed capacity of over 100 MW in Asia and an annual power generation of 119 MWh once operation begins

rate of large-scale grid connection ground PV power stations reached up to 92% and most of these power stations are in the western areas with abundant solar resources. Meanwhile, with the increasing maturity of PV power technology and the decreasing cost of PV cells, the mid-east region of China, where the economy is prosperous, is beginning to construct distributed PV power generation systems. By 2013, the installed capacity of distributed PV was 3.10 GW, accounting for 15.96% of the total installed PV power capacity [21].

According to China's 12th five-year plan, for solar power development, the future development trend for solar power will be the combination of the centralised and distributed utilisation modes. On the one hand, by 2015, the development of distributed PV systems combined with the construction in mid-east China will be the key project, for which the total installed capacity will be 10 GW; on the other hand, 10 GW grid-connected PV plants will be constructed in Qinghai province, the Xinjiang Uygur Autonomous Region, Gansu province, the Inner Mongolia Autonomous Region and other provinces with abundant solar and land resources, the main aim of which is to increase the power supply for local residents. We can see the specific development situation of MW-class PV plants outlined in the "Solar power 'twelfth five-year' development planning" [22] from Table 3.

3. Management mode of grid-connected REG in China

Given the increasing proportion of REG, the problem of grid connecting REG is most urgent, so we will explore the management mode of grid-connected REG in China in this section. Considering that wind power generation accounts for a large proportion of REG and that the problems for the grid connection of wind power are the most urgent, we will take the management mode of grid-connected wind power as being representative in this section.

3.1. Operation management

The management of REG is different from the management of conventional power generation. Renewable energy generation will have a significant effect on the peak regulation, voltage regulation, operation and many other aspects of the grid when large-scale REG projects are connected to the grid [23]. Therefore, the study of how to decrease the shock of introducing REG to the grid and how

to optimise the operation of grid-connected REG is urgently required. Taking wind power as an example, efforts are being made to optimise the operation of grid-connected REG in three phases: the early stage before grid connection, the launch of wind turbines and the late stage after grid connection.

(1) Planning work in the early stage of grid connection

In the early stage of grid connection, the national government is responsible for the pre-approval of plans. In 2011, the interim measures on the management of wind power development and construction was promulgated by the National Energy Administration, the measures of which regulate that wind power projects should implement an annual investment plan that undergoes a unified evaluation, with the project being executed according to the approved annual plan. According to the measures, for the large-scale wind power installations, independent plans must be made in advance for the line construction projects that enable access to the output of such wind power installations. On the basis of the study on the capacity of wind power distribution, transmission plans for the large-scale wind power installations in the northwest, north and northeast of China have been made currently, with transmission plans developed for the first-stage wind power base projects in Jiuquan, north Zhangjiakou and Chengde. The planning works for wind power bases in Hebei province, Kailu of Tongliao and Tongyu of Jilin province are ongoing. Transmission plans for the current eight wind power bases described in the "White paper of State Grid for promoting the development of wind power" [24] are shown in Table 4.

(2) Testing standards for grid connection of wind power during the period of launch of the wind turbines

During the period of launch of the wind turbines, on the one hand, efforts are made for the study of the relevant regulations for the testing of the grid connection of wind power, and the authentication and testing of the connection to the grid are mandated [25–27], with a list of standards described in Table 5. On the other hand, to meet the requirements of the testing of large-scale wind power that must be connected to power grid, the development of the capacity of grid connection testing is being strengthened. Currently, there are 9 provinces that have a qualified wind power testing agency, which enables the conducting of a test of the low-voltage ride-through capability, power quality, power regulation and grid performance among many other key indices of the wind turbines in many provinces, including Jiangsu province, Fujian

Table 4
Eight wind power bases and their transmission plans.

Wind power bases	Transmission plans	
	Transformer substations	Transmission lines
Hami, Xingjiang province	Newly constructed Naomao Lake and Santang Lake 220-kV substations with the existing Hami and south Hami 750-kV substations	Dispatched through Hami to Henan province using 800-kV DC lines and Hami to Shandong province 1100-kV DC lines
Jiuquan, Gansu province	Newly constructed Dunhuang, Southern Qiaowan 750-kV substations with the existing Guazhou and Yumen 330-kV substations	Dispatched through the Hexi Corridor 750-kV DC lines and the Jiuquan to Hunan province 800-kV DC lines
Hebei province	New constructed Kangbao, Shangyi, Jiefang, Lianhuatan and Yudaokou 500-kV substations	Dispatched together through the Zhangbei and Ximeng power substations
Jilin province	Newly constructed Tongyu, Xiangyang and Siping 500-kV substations with the existing Tianshui, Songyuan and Changling substations	Dispatched together through the north-east China grid
Western Inner Mongolia Autonomous Region	Newly constructed Baotou, Ulanchap and Ximeng substations	Dispatched through four EHV AC (alternating current) channels, from the west Inner Mongolia Autonomous Region to Jiangsu province and from Ximeng to Jiangsu province 1100-kV AC of the “Three-China Region” (north China, middle China and south China) load centre
Eastern Inner Mongolia Autonomous Region	Newly constructed Laofengkou, Zhurihe, Kailu, Yangshugoumen, Songshan and Southern Xingan 500-kV substations	Dispatched through the Hulunbuir to Shandong province, the Hulunbuir to northern Henan province and the Chifeng to Jiangsu province 800-kV DC lines of the “Three-China Region” load centre
Jiangsu province, Shandong province	The wind power in both Jiangsu province and Shandong province is decentralised in the eastern coasts, where the load level is high and the power grid is stable. Therefore, the wind power generated is primarily absorbed locally and dispatched through a voltage level of 500 kV and below	

Table 5
Regulations and standards for the grid connection of wind power.

Regulations and standards	Year	Departments	Contents
<i>Technology regulations for the access of wind farms to power systems</i>	2005	State grid, China electricity council	Formulates the requirements of the technologies that enable the access of the wind farm to the power system
<i>Technology regulations for the access of wind farms to power systems (revised)</i>	2009	State grid	Regulation that mandates that each wind farm should have the functions of power control, power forecast, low-voltage ride through, monitoring, communications etc.
<i>Technology regulations for the access of PV plants to the power system (trial)</i>	2009	State grid	Regulation that mandates that large- and medium-scale PV plants should have the characteristics of good power quality, the use of general technologies, active power output, active and reactive power control, and security protection
<i>Wind power dispatching management practices</i>	2010	State grid	Formulates the requirements for the management of the connection, debugging, power planning, maintenance planning, protection and security automation devices, operation of communication devices, dispatching automation, and other requirements for each wind farm
<i>Interim measures for the grid connection testing of wind turbines</i>	2010	National energy administration	Regulates the performance testing of the connection of wind turbines for wind-turbine manufacturers
<i>Anti-accident operation measure for the points of connected wind power (State Grid Dispatch CenterCentre (2011) 974)</i>	2011	State grid	Formulates the testing requests for the low-voltage ride through (LVRT) capability of wind turbines
<i>wind power test management measures by State Grid (trial)</i>	2013	State grid	Formulates the standards for the testing work of the connected wind power systems in the three aspects of management system, method and workflow

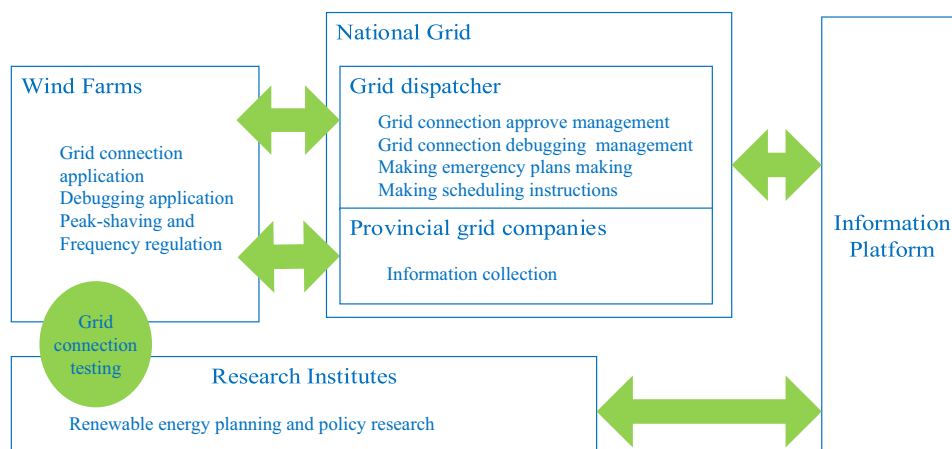


Fig. 3. Organisational structure for the management of the grid connection of wind power.

Table 6

Development of the policies of priority access to the grid.

Year	Policies	Contents
2003	<i>Franchise bidding system</i>	(1) Governments make commitments to ensure the grid connection and sale of wind power (2) Grid corporations are responsible for the investment and construction of transmission lines from the grid to the wind farms, which were previously the responsibility of the wind farms
2006	<i>Renewable energy act</i>	Mandatory access and full acquisition of renewable energy sources are defined
2006	<i>Relevant regulations for the management of renewable energy generation</i>	The responsibilities and property rights are defined explicitly, which is the basis of the mandatory access imposed by the <i>Renewable energy act</i>
2007	<i>Regulatory measures of the full acquisition of renewable energy generation for grid corporations</i>	The functional departments, responsibilities, measures and other aspects of electricity regulation in the full acquisition of REG are regulated
2007	<i>Management measures for the dispatch of energy-conservation power generation (trial)</i>	(1) REG should be dispatched preferentially and economically under the premise of a reliable supply of electricity (2) The order bit table for different generating units is formulated, with the first REG units being wind, solar and ocean energy, which are without the ability to regulate
2009	<i>Renewable energy act (revised)</i>	The provision of full acquisition is replaced by protective full acquisition
2013	<i>Interim Measures on Management of Distributed Generation</i>	Power companies are required to ensure priority access and full acquisition of excess distributed generation

province, Jilin province, Heilongjiang province and northern Hebei province [28].

(3) Dispatch and operation management for late-stage grid connection

There are three dispatch management modes for the connected wind farms in the State Grid: provincial dispatching, dispatching entrusted to the municipal grid and joint dispatching by both the provincial and municipal grids [29]. According to the laws and regulations, such as the *law of electric power of the Republic of China*, *dispatching management regulations of the power grid* and the *renewable energy act*, the State Grid formulated *wind power dispatching management practices (Q/GDW432-2010)*, which ensures the security and stability of the grid-connected wind farms [30]. The strengthening measures for the dispatching and operating of wind power plants are mainly embodied in three aspects: the construction of real-time monitoring systems for wind power, the strengthening of the management of professional wind power and the improvement of the forecasting accuracy [31].

3.2. Organisation management

To standardise the dispatching and the operational management of the grid dispatchers and the wind farms and to further realise the efficient mechanisms for the operation of grid-connected wind power, the State Grid established a hierarchical management structure [32,33], as shown in Fig. 3. The dispatching and testing of wind power is under the centralised management of the State Grid headquarters, while the provincial grids are responsible for establishing the information platform and collecting the information of the planning, preliminary, construction, grid connection operation and other basic information of the wind farms; the grid dispatcher is responsible for the management of the application, debugging and scheduling of the grid connection; it is the main work of the State Grid Energy Research Institute and the China Electric Power Research Institute to study the planning and policy of wind power development and to improve the testing for the grid connection of wind power to the grid.

3.3. Incentive policies

China has initially established a series of incentive policies to support the development of REG; these policies can generally be divided into three aspects: priority access to the grid, categorisation of the electricity price and cost allocation policies for REG [34]. To guarantee the adequate adoption of REG by the demand side,

from the perspective of the generation investment, grid acquisition and dispatch operation, the policies of priority access to grid were progressively formulated [35]. The details of these policies are shown in Table 6.

In addition, in October 2013, the National Energy Bureau proposed that wind power would be implemented of priority access and full acquisition in the next 2–3 years.

The REG electricity price experiences five stages, which is described in Table 7.

In addition, the cost allocation and subsidy incentives for REG have been revised and improved gradually, from which we can see that the support for the development of REG is becoming increasingly normalised and diversified [36,37]. Table 8 presents the cost allocation and subsidy incentives for REG.

4. Main problems of the management of the grid connection of REG

Although a complete set of grid connection management modes of REG has been established in China, problems remain in the operational management, organisational management and incentive policies that impede the orderly deployment of large-scale grid connection of REG. This section will analyse the existing problems of the grid connection management of REG in China from the above three aspects, taking wind power as an example.

4.1. Operational management

- (1) The power system faces potential security risks because the electricity performance testing capability is not adequate for the wind turbines to be connected to the grid. The connection of large-scale wind farms to grid requires the controllability of wind power to ensure the security and stability of the power system. However, the majority of the wind turbines operating and connected to the grid do not have testing certification and do not meet the technical requirements to be connected to grid, resulting in the potential safety hazard of the power system. For example, wind turbines without the capability of low-voltage ride through will disconnect from the power system when a system disturbance occur, which will make the system suffer a second shock and thus expand the scope of the possible accidents in the grid.
- (2) The lack of capacity of peak shaving and frequency regulation results in an inadequate safety margin for wind power in the grid. The load difference between the peak and the valley is

Table 7
Categorised electricity price for REG.

Stages	Name	Notes
Early 1990s–1998	complete competition for access to the grid	During this stage, the generation equipment was purchased with the aid of foreign funds and the pool purchase price was so low that tariff revenues were only sufficient to maintain the operation of wind farms. A tariff was approved by the local price authorities and reported to the central government for the record. The electricity prices for REG during this stage were diverse, ranging from ¥0.2 /kWh to over ¥1 /kWh. The demarcation point between this stage and the previous stage is the first set of programs executed by concession bidding, and from then on, the bidding price and approval of the tariff existed simultaneously. The wind programs launched by the central government was executed by concession bidding, the bidding was held three times by 2005, while the programs launched by the provincial and sub-level government still adopted the approval of the tariff. This landmark involved the enactment of <i>renewable energy act</i> in January of 2006 and the <i>measures for renewable energy generation electricity price and cost allocation management</i> among other relevant policies. Notification about the improvement of the policies of grid connection of wind power that regulates the electricity tariff of four regimes, which are divided according to the resource status.
1998–2003	Approval of a tariff	
2003–2005	Coexistence of the bidding and approval of the tariff	
2006–2009	Bidding with authorisation	
2009–now	Fixed price	

Table 8
Cost allocation and subsidy incentives for REG.

Year	Polices	Contents
2006	<i>Proposed trial measures for the renewable energy generation electricity price and cost allocation management (trial)</i>	Regulates the additional revenue levied for REG will be paid for the subsidy of the grid connection of REG
2007	<i>Interim measures for the deployment of the additional revenue from the tariff for renewable energy</i>	Regulates the process of management, regulation and operation for the levy and the use of the additional revenue from REG
2012	<i>Interim measures for the management of the additional grant funds from the tariff for renewable energy</i>	Regulates the allowance standard for REG access to the grid

currently 30% in China [38], with the difference even reaching up to 40% in some regions. Although methods currently exist to mitigate the load difference by peak shaving, the peak-shaving capacity of thermal power is limited, while the majority of hydro-power plants are “run of river stations” that do not have the capacity of peak shaving during the dry season; as a result, the capacity of peak shaving of the current generation capacity is limited [39]. The peak-shaving capacity will be worse when large amounts of intermittent wind power are connected to the grid. In addition, load forecasting work has not been performed by most of the wind power plants, so the dispatcher cannot consider the impacts of wind power, thereby reducing the adequacy of the power system safety.

4.2. Organisational management

- (1) Disorderly development exists in the construction of wind farms due to the lack of coordination in the planning of local management departments. It is common that the total planned capacity determined by the preliminary work of wind investment exceeds the scale planned by the local government, and the scale of the local government plan is always larger than that of the national plan. The reason for this phenomenon is the lack of study of the market adoption of wind power when the local government produces wind power development plans, while the main basis of these plans is only the local wind power resource available [40].
- (2) Plans for implementing power generation and the power network are uncoordinated, which causes a situation where electricity cannot be delivered from some sources. China's REG is mainly located in the northwest of China, north China and northeast China, where the electricity demand and the level of development of power grid are both low, so the distribution of REG is high where the power demand is low in China [41].

Wind power has the characteristics of “large-scale centralised development and long-distance transmission”, so it must be transmitted through long-distance and high-voltage power grid to load centre. The uncoordinated plans for power generation and the power network as well as the uncoordinated construction of power plants and of the power grid make the development of transmission capacity unable to catch up with the rapid development of wind power [42]. For example, the average annual utilisation hours of wind power was 2080 in 2,013,190 h more than that of 2012 and in some regions, the utilisations were even less than 1400. The abandonment of wind power is serious [43,44]. In Northeast China, North China and Northwest China, this situation is more serious than other places. Among those, Eastern Inner Mongolia and Jilin province are the most serious areas with the proportion of wind abandoned exceeding 20%. Besides, the proportion of wind abandoned in Western Inner Mongolia, Gansu province and Heilongjiang province also exceeds 10%. This situation will also lead to the reduction of wind power generation, in turn, it will lead to the energy waste as well as the environmental pollution. The situation of abandoned wind in China during 2011–2013 [45] is shown in Table 9.

- (3) The management mechanism for the operation, grid connection and dispatch of wind farms is not complete. For example, supervision of some of the lowermost grid corporates during the grid connection of wind farms is poor, with some wind farms being allowed to connect to the grid without a security assessment; in addition, the organisation and management for wind farms is not standardised, and the management of reactive and secondary systems cannot meet the safety requirements of the power grid [46]. Additionally, wind power project management is lacking, resulting in some projects being divided into some minor ones with a much smaller scale, which hinders the implementation of a unified plan for the grid connection of wind farms.

Table 9

Situation of abandoned wind in China during 2011–2013.

Year	Wind abandoned (billion kWh)	Proportion (%)	The average utilisation hours of wind power (h)	Amount equivalent to the loss of standard coal (million tons)	Equivalent to the growth of CO ₂ emissions (million tons)
2011	10.0	12	1920	3.3	10.0
2012	20.8	17	1890	6.9	20.8
2013	16.2	11	2080	5.4	16.2

4.3. Incentive policy

Although China is gradually completing the supporting policy framework of REG because of the short implementation time, the implementation is still evolving. The following policy defects exist.

- (1) Full acquisition for REG fails to consider the safe, economic and stable operation of the network, which is not conducive to the sustainable development of the grid connection of REG. From a global perspective, full acquisition of REG is adopted by all the countries during the early stages of REG development. With a further study of the overall technical economy, legislations for REG in developed countries are undergoing the transition from full acquisition to priority acquisition [47]. In China, the scale of wind power connected to the grid is not large at the early stage and it does not have a significant impact on the power system; thus, full acquisition of REG is currently possible in the development of REG in China [48]. However, when large-scale wind power is connected to the grid, it requires a significant cost to guarantee full acquisition of wind power, especially in the areas of the northeast, north and northwest of China, where a single generation structure and a limited capacity of peak shaving can lead to the implementation of some uneconomical and unsafe methods with the implementation of wind power, such as the turning off of thermal power generating units.
- (2) Inadequate subsidy for the grid investment of REG
 - 1) The subsidy for the development of REG tends to provide more support to the field of generation, while the electricity transmission and ancillary services market receives less attention. In the *Interim measures for the deployment of additional tariff revenue of renewable energy*, the subsidy is assigned only to the transmission projects for REG that are accessed and terminated in the local area. In addition, the level of subsidy for these electricity access projects is generally too low to meet the requirements of the investment and maintenance of these transmission projects. It is this lack of a rational tariff mechanism for transmission projects of the large-scale wind base that makes it difficult for returns for investment in such projects. In addition, the related pricing and compensation mechanism for other ancillary services, such as peak-shaving, frequency adjustment and pressure regulating, results in a failure to build up such services.
 - 2) The grid connection policy does not give full consideration to the entire power system, and there is not a systematic arrangement for the adoption of REG. On the one hand, the level of subsidy is just for REG that is locally or inner-provincially connected and adopted, yet the subsidy for the inter-provincially or inter-regionally adopted REG is not considered, nor are the ancillary services to wind, solar and other intermittent REG using conventional power sources considered. On the other hand, most grid connection policy is a restrictive requirement to power the grid; however, the generation side (REG) is not subject to the grid connection policy [49]. For example, suitable technology standards for grid connection of REG have not been formulated nationwide, so the generation

Framework of Coordinated Management Mechanism for Orderly Grid Connection of REG

Coordinated Management Mechanism for Integrated Planning

- Coordination of planning for multiple management sectors
- Coordination of planning for REG and power grid
- Coordination of planning for REG and peaking shaving generation
- Coordination of power source planning and power consumption planning

Coordinated Management Mechanism for Transmission of Grid-connected REG

- Coordinated management mechanism for orderly grid connection of diverse REG
- Coordinated management mechanism for orderly grid connection of REG and conventional energy generation
- Coordinated management mechanism for orderly grid connection of REG and large scale energy storage

Fig. 4. Framework of the coordinated management mechanism for the orderly grid connection of REG.

equipment manufacturing enterprises of REG power have no impetus to develop and produce generation units that can meet the requirements of the grid. In addition, because there is no regulation for REG farms to forecast REG and the grid corporations have no rights to require wind farms to perform forecasting, there is no incentive for the wind farms to perform forecasting themselves.

5. Coordinated management mechanism for the orderly grid connection of REG

It can be concluded that the existing problems in the operation, organisation and incentive policies that have led to the abandonment of some REG and the inefficiency of the energy utilisation. To solve these problems, corrections must be made to the integrated planning for the grid connection of REG and the coordinated mechanism for the transmission of grid-connected REG.

The framework of the coordinated management mechanism for the orderly grid connection of REG is shown in Fig. 4.

The coordinated management mechanism for the integrated planning consists of four aspects: coordination of the planning for multiple management sectors, coordination of the planning for REG and the power grid, coordination of the planning for REG and peaking-shaving generation, coordination of the power source planning, and the planning of the power consumption. The coordinated management mechanism for the transmission of grid-connected REG consists of three aspects: the coordinated management mechanism for the orderly grid connection of the diverse sources of REG, the coordinated management mechanism for the orderly grid connection of REG and conventional energy sources, and the coordinated management mechanism for the orderly grid connection of REG and large-scale energy storage.

5.1. Coordinated management mechanism for the orderly grid connection of REG

To facilitate an orderly grid connection of REG and a better use of REG, the following aspects should be considered thoroughly:

(1) Main participants

The development of REG is a complicated project, which requires the coordination among multiple sectors and multiple participants, including the departments of energy and power, the departments of meteorology and resource, the department of transportation and other departments, in addition to power grid corporations, power generation groups, local governments and the provincial power companies are all the participants in the development of REG.

(2) Processes of planning

Systematic development of REG determines the close links in the processes of planning, consisting of comprehensive information database planning, REG base planning, power generation and grid planning, and coordination and cost-allocation programs, etc.

(3) Content of planning

Comprehensive information involving power and other related areas should be considered in the REG planning. To ensure full use of REG, planners could implement integrated planning with more attention to meteorology forecasting techniques, generation base construction, coordinated planning of conventional and peak-shaving generation, grid development, the local economy and the power status.

A coordinated management mechanism for an orderly grid connection of REG is shown in Fig. 5.

In the left part of the picture are the participants involved in the coordinated management mechanism; in the middle part are the planning work and transmission scheme of REG to be connected to grid; in the right part is the detailed output of the coordinated management mechanism. Specifically, the middle part consists of three smaller parts: the first part is the comprehensive information database planning, the second part is the integrated planning for the generation base, the generation expansion and the power grid, and the third part is the transmission and adoption of REG, planning for the return on investment and the cost allocation.

5.2. Solution to the problems of the orderly grid connection of REG with a coordinated management mechanism

This section will explain how to solve the problems of the grid connection of REG with a coordinated management mechanism. The principle of two mechanisms will be discussed further.

5.2.1. Coordinated management mechanism for the integrated planning of REG grid connection

For REG grid connection planning, the coordinated planning of multiple departments among REG, power source and power grid, REG power sources and peak-shaving power sources, power sources and power consumption are all required.

(1) Coordinated management mechanism for REG planning among multiple departments

Currently, the participants of REG planning consist of local government, power grid corporations, provincial power companies and REG investors, whose REG plans are formulated separately according to independent information resources and investment conditions. Plans made by these participants

differ in scale, layout, sequence and other aspects; thus the development of the power grid and conventional generation would not meet the requirements of grid connection of REG to contribute to the development of REG. To solve these problems, we propose the coordinated management mechanism for REG planning among multiple departments, as shown in Fig. 6.

In the mechanism, the power grid is the key factor responsible for coordinating the other factors, where detailed outputs including the REG development plans should be integrated. The power grid will make plans for conventional generation and peak-shaving generation according to the output of the other sectors. Finally, plans for REG, the power grid, conventional generation, and peak-shaving generation should be audited together. The planning process was generally converse to the proposed mechanism in practice.

(2) Coordinated management mechanism for REG power source planning and power grid planning

To meet the requirements of large-scale development and full use of REG, planning for REG and the power grid should be unified. Therefore, a grid-development framework is developed to coordinate with the development of REG, as shown in Fig. 7.

From this figure, in each process of power grid planning, the planner should pay more attention to the following elements. On the generation side, resource distribution and generation characteristics should also be considered in the power grid plans; in the transmission process, large-scale and long-distance transmission capacity is required, which is the primary constraint for large-scale development of REG; on the demand side, to integrate the demand-side resources into the power grid planning and realise the intelligent control of loads with DSR are the great challenges for the power grid. The specific state of how to use DSR to promote the adoption of REG will be given later.

(3) Coordinated management mechanism for the planning of REG power sources and peak-shaving power sources

After the coordination of the planning for generation and the power grid, this section will introduce the coordination among the different planning aspects for power generation. The approach of improving the REG power forecasting and technical performance of REG units can just improve the capacity of REG to fit the requirements of network operations; however, this approach cannot remove the impact due to the intermittent nature of REG fundamentally. Therefore, during REG planning, REG and other power supply sources must be considered and planned in an integrated fashion, especially for the siting and construction of pumped-hydro storage, gas-fired generation and other power sources with excellent regulation capability. In addition, thermal power generation units with deep regulation capability should be considered. Meanwhile, the connection of the networks among different regions should be strengthened to promote the overall regulation capability of the networks to adapt the large-scale development of wind power and PV power.

Currently, in national grid of China, many regions have implemented development plans for REG bases. Development plans for peak-shaving generation, however, cannot match the development of the REG bases. As a result, national planning for peak-shaving generation should be implemented to guide regional plans, upon which local planners can formulate their development goals with consideration of the local resource conditions. For example, the Xinjiang Uygur Autonomous Region is abundant in wind and solar power, while the conventional power generation is primarily small-scale thermal generation, heating thermal generation and run-of-river

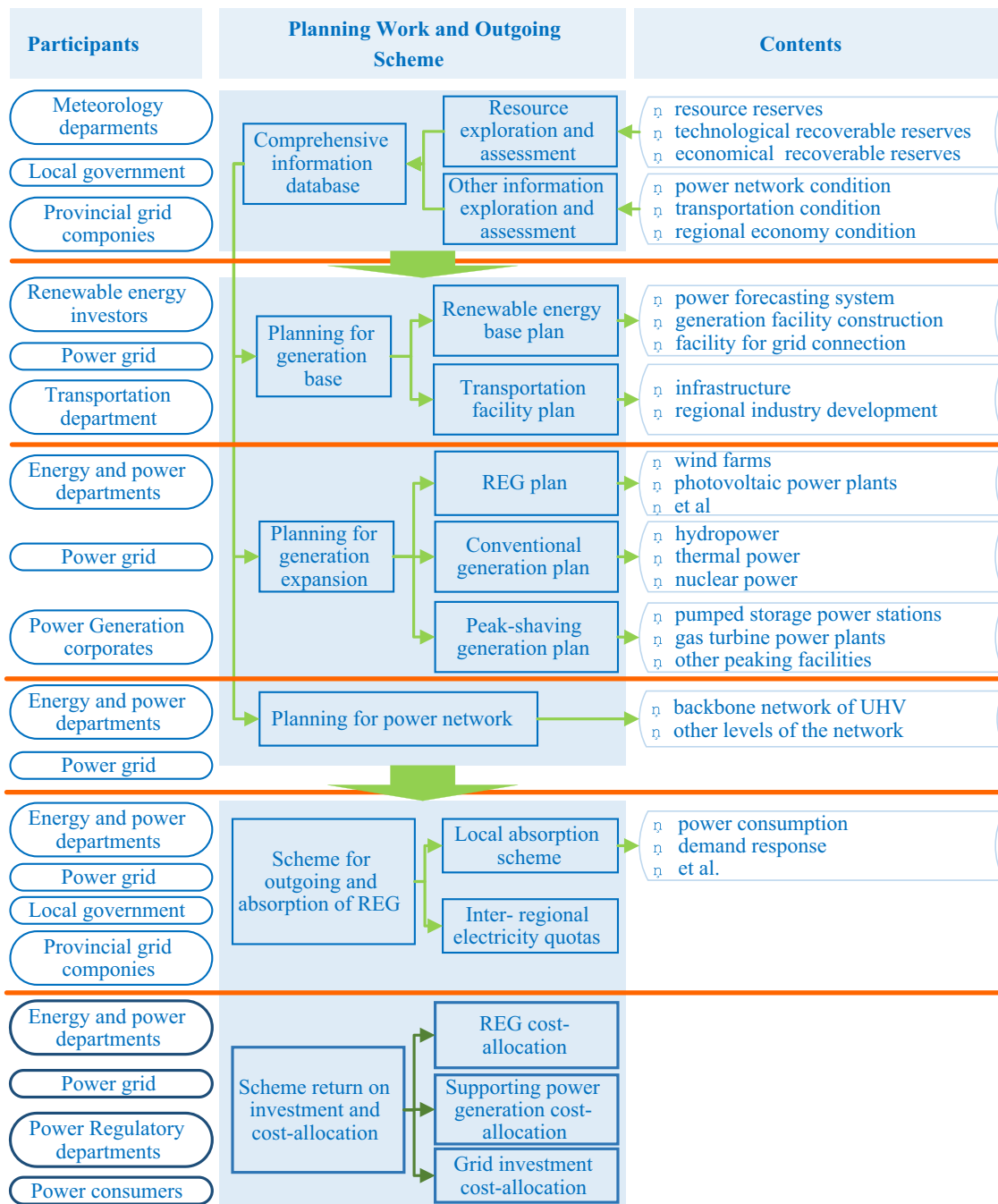


Fig. 5. Coordinated management mechanism for orderly grid connection of renewable energy.

hydropower, which indicates that wind and solar power in the Xinjiang Uygur Autonomous Region does not have sufficient reserves to regulate power fluctuation. However, from another perspective, the Xinjiang Uygur Autonomous Region has the largest natural gas reserves in China, so gas power generation can become a higher priority in the power planning of the Xinjiang Uygur Autonomous Region. In this case, pilot programs for the bundled generation of combined wind, thermal and gas power can be first applied in the Xinjiang Uygur Autonomous Region.

(4) Coordinated management mechanism for the planning of REG and energy use

The National Grid has proposed the idea of general use of REG; in summary, “constructing large scale bases and facilitating the connection of REG to grid step by step”, which can be taken

as the foundation of the use of REG together with the coordinated management mechanism for the planning of REG bases and the power grid mentioned above. Further, the tariff policy for the power market and the REG quota system can be improved at the same time. Some detailed and additional measures are as follows:

- 1) Implementing multiple demand-side absorption programs
When forming a plan for the use of REG, multiple programs consider that DSR can be integrated. By means of price signals and incentive mechanism, DSR can decrease the quantity of power consumption in short period actively. And customer or the combination of customers can guarantee decreasing their power load during a specific time period. On the one hand, for load resources which can be cut down, DSR can reduce the total consumption quantity to realise power saving. On the other hand, for load resources which can be transferred, DSR can transfer

The problem of transmission cost can be accounted for by the regional electricity price difference. Therefore, the cost of using REG can adopt the principle of sharing the cost equally. The system cost, including not only power facilities construction costs but also other costs paid by the entire power system to absorb the intermittent REG, should also be incorporated into the cost accounting of power grid construction. Part of the electricity price revenue could be classified into local financial revenue. In addition, local revenue from REG purchased inter-regionally could be shared after the negotiations between both sides.

5.2.2. Coordinated management mechanism for the output of grid-connected REG

In terms of the coordination of the output of grid-connected energy, we must conduct research on coordination problems, such as the complementary output of diverse REG sources, coordinated delivery of renewable energy and conventional energy and the coordinated delivery of renewable energy and large-scale power storage devices.

(1) Coordinated management mechanism for the orderly grid connection of wind/solar and other REG

Wind and solar energy are both intermittent and random, and it is difficult for their stand-alone power supply systems to provide continuous and stable power output. To obtain the stable output of the power supply, wind-solar hybrid electric systems with energy storage devices can be used, which can make full use of the natural complementarity between wind and solar energy in time and geography; in addition, the use of storage devices can improve the power output characteristics of a wind-solar hybrid system, also enabling relief from the intermittent and volatile nature of REG, thereby achieving the real-time balance of a power system.

In the operation of a wind-solar hybrid power generation system, we first must determine the scheduling of the objectives of the system and the scheduling strategies. The scheduling objective and the scheduling strategies of a wind-solar hybrid power generation system are described in Table 10.

The dispatch process of a wind-solar energy storage hybrid system mainly consists of the joint power prediction of the wind-solar hybrid power station, power generation scheduling and real-time generation control, as shown in Fig. 8.

1) Joint power prediction of a wind-solar hybrid power station. The prediction is based on meteorological information, such as wind speed and illumination, and utilises the historical operation data of the Wind farms and the PV power stations through supervisory control and data acquisition (SCADA). Subsequently, a certain output power evaluation model is established. The model will predict the output of the wind farms and the PV power plants for the next day using a variety of methods, and then determine

the total output power curve of the wind-solar hybrid power station for the next day.

- 2) Power generation scheduling through an intelligent control dispatching system. First, by inputting the predicted output curve of the wind-solar hybrid power station that is determined from the prediction system and then offering a variety of optimal control objectives, dispatchers can arrange the output plan of power system reasonably in advance and determine the planned output power curve of the wind-solar hybrid power station for the next day.
- 3) Real-time generation control is based on the actual output of the wind-solar hybrid power station and other real-time monitoring data. The difference between the planning output and the actual output will be calculated in real time, with the system able to automatically adjust the output of wind power and PV power to make the actual output of a wind-solar hybrid power station as close as possible to the planned output.

(2) Coordinated management mechanism for the orderly grid connection of REG and conventional energy

The random and intermittent wind power makes it difficult to control the wind power output. If there are a certain number of conventional units that can cooperate with REG units, the compensation of the wind power output can be achieved and the intermittent fluctuation of wind power will be stabilised with the adjustment ability of hydropower and thermal power units. In addition, the compensation will also guarantee the outgoing load characteristics to meet the requirements of the receiving-end grid and transform inferior energy into high quality and clean electric energy that can be accepted by the receiving end. Therefore, while strengthening the power-grid construction and accepting more connections and outputs of wind power, the complementary outgoing mode of wind-thermal-hydro power can be implemented to produce stable power flow.

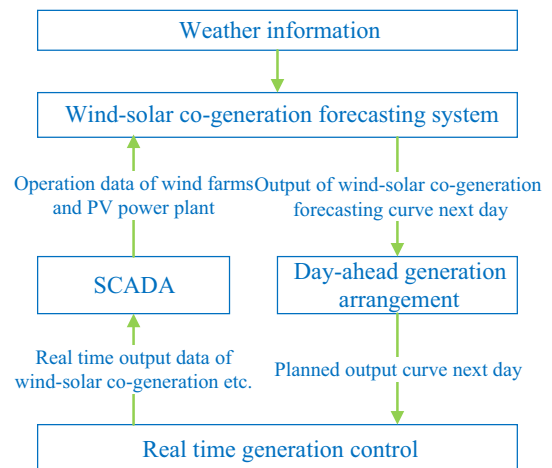


Fig. 8. Scheduling processes of a wind-solar energy storage hybrid system.

Table 10
Scheduling objectives and strategies of a wind-solar hybrid power generation system.

Objectives	Contents	Strategies
Smooth the power output curve during the process of power generation	To inhibit fluctuations of wind and PV power generation in the short-term and long-term and to increase the stability of the output of renewable energy through the joint scheduling of wind and solar and the storage and release of electricity using storage devices	Calculate the total power output curve of a wind-solar hybrid power generation system according to the wind speed and the predicted data of light intensity, and thus to develop a charging and discharging strategy of an energy storage system
Tracking the planned power output curve	Control charge and discharge process of storage battery according to planned power output curve to make actual power output of the plant close as possible as the planned power output curve and increase consistency of renewable energy output	Determine the prediction output curve of the system according to the predicted data of wind speed and light intensity

Table 11
Operation management strategies of the joint dispatch of wind power and conventional energy generation.

Conditions	Operation management strategies
Hydropower is involved in the joint dispatch	With the joint operation of hydropower and wind farms, hydropower can be used to compensate for the short-term fluctuations of wind power, and wind power provides a guarantee for the combined power generation system with sufficient power
No hydropower is involved in the joint dispatch or the hydropower is insufficient to balance the wind power output	Thermal power is viewed as the primary peak shaving method for balancing wind power output. First, calculate the peak-shaving capacity of hydropower for wind power (the capacity is 0 if no hydropower is involved in the joint dispatch). Then, arrange the operation point of all types of thermal power plants in the system load curve

There are two main joint dispatch modes of wind power and conventional energy generation. The first mode is to determine the outgoing proportion and the prices of each region through multilateral consultations. According to the operating characteristics and tariff levels of wind power, thermal power and hydropower in a specific area, grid companies can consult with the power generation companies and local governments to determine the proportion and outgoing prices of wind power, thermal power and hydropower. The second mode is to promote agency transaction and the auto transfer of power transmission rights, where the power transmission contract is viewed as “power transmission rights”. First, the thermal power enterprises and hydropower enterprises will submit a long-term outgoing commission price. Then, the thermal power and hydropower enterprises must determine day-ahead generation scheduling at the planning day of the thermal power and the hydropower according to the load forecasting, wind power forecasting, tie-line scheduling, maintenance planning and so on. When there is a deviation between the predicted output and the actual output of wind power, the dispatch department will dispatch thermal power and hydropower to compensate for the power imbalance as required, and then achieve the auto transfer of the power transmission rights. Operation management strategies of the joint dispatch of wind power and conventional energy generation are described in Table 11.

- (3) Coordinated management mechanism for the orderly grid connection of REG and large-scale power storage devices
- With China's rapid development of wind power generation, coordinated planning operation of wind power and pumped-hydro storage power stations has been one of the key issues for the effective implementation of China's new energy development policy. Because of the static and dynamic capabilities of pumped-hydro storage power stations, such stations are urgently required by the grid to ensure its security, stability and economic operation. However, it is not the case that more pumped-hydro storage power stations are better because a coordinated planning management is required for the joint dispatch of wind power and pumped-hydro storage power stations. Only with a reasonable proportion of each part of a wind-hydro system can the effectiveness be optimised.

1) Combined system of wind and pumped-hydro storage

There are three main structures of a wind and pumped-hydro storage combined system. The first structure is that wind power is only connected to a pumped-hydro storage power station. The second structure is that wind power is connected to both a pumped-hydro storage power station and the grid. The third structure is that wind power is only connected to the grid. Considering the special geographical conditions and the power energy efficiencies of both wind power and pumped-hydro storage power stations, the most flexible option is that both wind power and pumped-hydro storage are connected to the grid. Therefore, the wind and pumped-hydro storage combined system structure shown in Fig. 9 is chosen in this section.

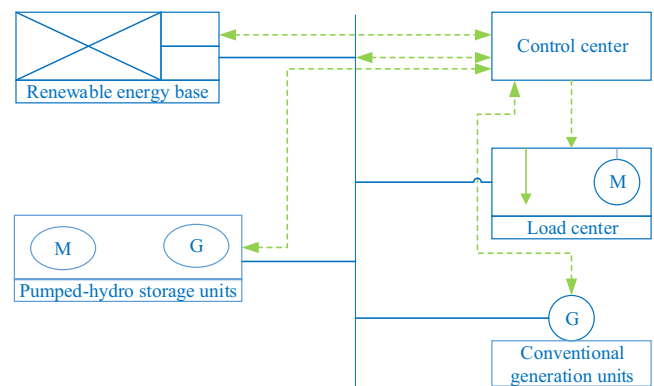


Fig. 9. Structure of a wind and pumped-hydro storage combined system.

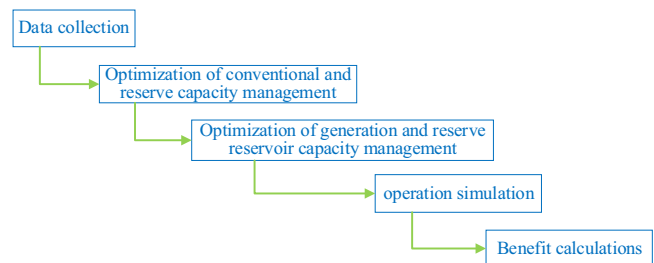


Fig. 10. Coordinated optimisation management process of the joint dispatching of a combined wind and pumped-hydro storage power station for the design level year.

The dashed line in the figure represents the signal line, while the solid line represents the electric power circuit. The output power of the wind turbines is limited by the wind speed and the installed capacity of the wind farms. The pumped-hydro storage power station has two operating states, pumping and generating, and its output is restricted by the capacity of the pumping and generating units and the capacity of the upper and lower reservoirs.

- 2) Coordinated management mechanism for the joint dispatch of a combined wind and pumped-hydro storage power station

Coordinated management mechanism for the joint dispatch of a combined wind and pumped-hydro storage power station mainly includes two parts. One part is the coordinated management plan of the wind power system and the corresponding pumped-hydro storage power station. The coordinated management plan for the pumped-hydro storage power station that has been built primarily includes three parts: the capacity dividing plan for the generation and the reserves, the reservoir capacity dividing plan for the generation and reserves, and the reserve capacity dividing plan for emergency and load.

Wind power and load demand are both uncontrollable and stochastic in the combined wind and pumped-hydro

storage system, so the coordinated optimisation management of the joint dispatch of wind and pumped-hydro storage power station mainly includes two parts: (1) the capacity optimisation management for the generation and the reserves and (2) the reservoir capacity optimisation management for the generation and the reserves. The process of coordinated optimisation management for the design year is shown in Fig. 10.

First, the process involves the preparation of data, including data of a particular wind farm in a wind-hydro system of a level year, the data of a pumped-hydro storage power station that is to be optimised and the data of its dynamic characteristics, and the data of system power generation and the data of its dynamic characteristics. Second, the process involves the optimisation management of the generating capacity and the reserve capacity of the joint dispatching of a combined wind power and pumped-hydro storage power station on the basis of their situation. Again, the management of the reservoir capacity of the generation and the reserves should be optimised according to their situation. Finally, the process involves the simulation of the joint dispatching operation of the combined wind power and pumped-hydro storage power station and the calculation of the static benefit and the dynamic benefit of pumped-hydro storage power station.

3) Coordinated management mode of REG and DSR

In addition to the dispatch of REG systems in the power supply side, REG such as wind power can coordinate with the DSR approaches for example, cold storage devices, thermal storage devices and electric vehicle energy storage. Taking a thermal storage facility as an example, it has advantages of low energy consumption, low cycle cost, long life cycle and is insensitive to the levels of the ability compared to the other power generation technologies. When the power system load is low and the wind power output is high, a thermal storage facility can also absorb the excess wind power to avoid abandoning wind power to make a full use of the available wind resources.

6. Conclusions

Currently, REG in China has experienced rapid development. Although the issue of grid connection rate exists worldwide, it is particularly severe in China. First, the resource distribution and technological level results in the difficulty of grid connection objectively. Besides, the imperfection of management mechanism is another important reason. Concerning the above issues, this paper first elaborated the situation of planning and construction of REG in China. Then, the grid connection management mode of REG was studied from three aspects: operation management, organisation management and incentive policy, and the existing problems of each step were analysed. Finally, a coordinated management mechanism was proposed with full consideration of China's resource endowment, technology level and power system to promote an orderly large-scale grid connection of REG sources.

The design fist sorts the participants, the planning process and planning content during the grid connection process and subdivides the planning process into three parts according to chronological order. On this basis, the ultimate coordinated management mechanism for the orderly grid connection of REG is proposed with two sub-mechanisms, the integrated planning coordinated management mechanism and the transmission coordinated management mechanism. For integrated planning, the mechanism establishes the coordinated planning of multiple departments among REG, the power source and the power grid, the REG power sources and the peak-

shaving power sources, and the power sources and power consumption. For planning the outgoing REG, the mechanism establishes the coordinated management of the orderly grid connection of wind/solar generation and other REG, orderly grid connection of REG and conventional energy, and the orderly grid connection of REG and large-scale power storage devices. The mechanism covers the existing issue of grid connection management in China comprehensively and has important reference for decision makers. With the application of it, an orderly large-scale grid connection of REG will be achieved gradually and the usage efficiency of energy and power will be improved.

It should be noted that the study is based on the conditions of China. Therefore, the proposed mechanism is of particularity. For example, power generation in China is independent from the transmission, distribution and sale, while in Japan all the links are of vertical integration. And this situation results in the inapplicability for some country in the dividing of rights and liabilities. Therefore, when formulating the management mechanism for the grid connection of REG, researchers should combine the situation of their own country.

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